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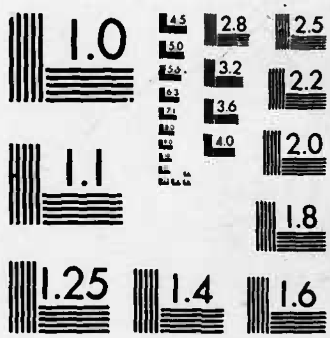

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PRECISION INSTRUMENT ENGINEERING

(Selected Articles)

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PRECISION INSTRUMENT ENGINEERING

Usage of CCD Sensors in Image Processing Tasks

- G. Seifert, Graduate Engineer
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  Academy of Military Medicine, Institute for Radiology

In many areas of research and technology, the processing of image data plays an important role. Moreover, a large part of known image processing systems is based upon the usage of television technology which, as is well known, has reached an extremely high technical level. An important component of the image processing system is the optical-electronic converter, whose properties influence in a decisive manner the operational possibilities, the extent of usage and the quality of the system.

The development beginning at the end of the 1960's in semiconductor technology in the area of charge transfer circuits and the technical implementations already achieved permit us to expect that solid state image receivers will replace the image orthicons to an ever increasing degree. EAST GERMANY (JES)

The physical basis, technologies and usages of charge coupled circuits are described comprehensively in the literature [1] to [10]; in this report, therefore, they will only be summarized.

1. Charge Coupled Circuits

Charge coupled components function in thermal non-equilibrium. In them, the information will be transferred along the surface of a semiconductor by charge packages consisting of minority charge carriers. The electrodes controlling this charge transfer receive suitable timing voltages in a cyclical sequence. The feature of the CCD concept is the ability to transfer analog signals generated electrically or optically.

The sensor matrix (Figure 1) used in the Research Center for Molecular Biology and Medicine exhibits a structure of 190 columns and 244 rows. The size of the light sensitive individual sensors is 12 micro m in the horizontal direction and 18 micro m in the vertical direction with an average separation of the elements from one another of 30 micro m in the horizontal direction. Optically covered vertical shift registers are located between the light sensitive columns to transfer the information from the light receivers into the horizontal read-out register. The sensor matrix is organized according to the Interline Transfer principle. That means, with each timing pulse ϕ on the photo gate, the generic charges are overwritten in the adjacent vertical register from the light sensitive cells. With each vertical timing pulse ϕ the transfer of the charges occurs later row for row in the horizontal register. In the period between the vertical timing pulses, the charges in the horizontal register with ϕ are transferred to the output amplifier. Figure 2 shows the entire and necessary timing diagram. It can be achieved through the proper arrangement of the potentials on the vertical timing performances during the minimal level of the photo gate voltage that either the charges are overwritten only from the odd-numbered or only from the even-numbered rows. Thus, we obtain two half images corresponding to the interlaced scanning typical in television technology. The output amplifier at the end of the horizontal register is assembled as a floating gate amplifier. It supplies a signal voltage proportional to the charge packages in the charge transfer channel and timed to the horizontal frequency. The output amplifier contains a scanning and restraining circuit to suppress the horizontal timing.

2. CCD System Assembly and Operation

An image system was developed on the basis of CCD sensors. The system is favorably compatible in each case with the requirements of the desired application, exposure relations, data processing speed and other influential factors. In this report a prototype of such an image device will be introduced. The device is conceived especially for usage in automated digital image processing. In this regard, attaching the CCD camera to a computer takes place via the Interface System "CAMAC" [11] suitable for laboratory and experimental automation. That determines also the modular design of the system (first introduced in [12]). Up to now, the implemented components are the camera and a CAMAC module to control the camera and capture the primary image data. As "search monitor," any typical cathoderay oscillograph can be used which allows an extreme modulation of its beam intensity.

CCD Camera:

The camera size is 190mm X 100mm X 80mm (without the lens). All Practica lenses can be used with the lens attachment M42 X 1. Attaching the camera on the corresponding microscope is also possible without any difficulty with the Practica adapter.

The camera (Figure 3) contains, besides the sensor matrix, a video preamplifier with a cable connection, gain convertors for control timings and variable voltage sources to adjust optimal timing amplitudes. The power supply (+ 5 V, + 15 V and -15 V) and the timing pulse (horizontal timing, vertical timing, photo gate timing) in the TTL gain are fed to the camera via a flat cable.

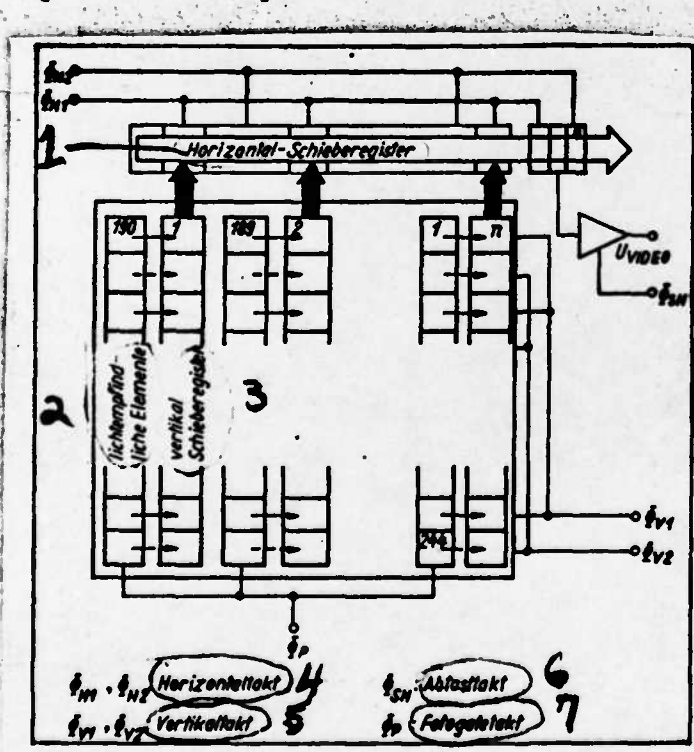

Figure 1. Schematic Structure of a CCD Sensor Matrix (U_{video} Output Image Signal)

1. Horizontal Shift Register
2. Light Sensitive Elements
3. Vertical Shift Register
4. Horizontal Timing
5. Vertical Timing
6. Scanning Timing
7. Photo Gate Timing

CAMAC Camera Module (Figure 4):

The module satisfies two objectives: controlling the camera and the actural interface implementation. These function are circuit technically implemented on two conductor cards.

The camera control and serves the genericalness of the various timing signals for the sensor matrix. In this regard, a single (variable) oscillator synchronizes a row of numbers with which the necessary timing sequences are produced. At varying frequencies, the same timing is, therefore, always guaranteed. The conductor card conditions, furthermore, two saw-tooth voltages for a analog image representation. These sweep generators are implemented with digital to analog converters. That means, of course, a greater effort compared to analog saw-tooth generators; however, it saves adjusting the charging time constants during changing of the timing frequency. In exchange, the delayed sweeping trigger can be advantageously released allowing the interlacing.

A video terminal amplifier conditions the video signal in such a manner that, as a result, the intensity control of a cathoderay oscillograph can take place. The amplifier (Figure 5) consists of a difference amplifier from the transistor array B 340 D and a dual gate MOS transistor on whose second gate the darkness control takes place during the horizontal and vertical synchronization.

The interface card has the CAMAC specialized command processing for initialization and execution of the image data transfer and for setting up the varying operational modes.

The video signal is supplied to a comparator whose reference voltage is either internally adjusted or is externally supplied under computer control. The present configuration uses to this end a CAMAC digital to analog converter module (DAC 5322 from ZfK Rossendorf). The output signal of the comparator is on the data inputs of two serial parallel decoders which function in a multiplex operation in order to ensure continuous data acceptance. The data word formed in the serial parallel decoder is switched via a multiplexer from 16 bits to the read lines R1 to R16 of the CAMAC data buss. Writing the data into the serial parallel decoder occurs with a strobe pulse derived from the horizontal timing $\overline{\Phi_m}$ and appears a defined period after its low high side. This timing delay guarantees the scanning of the comparator output at a time in which the video signal is resonating following the scanning and restraining pulse $\overline{\Phi_m}$ on the sensor and cross talk distortion signals, in particular from the sides of the horizontal timing, are sufficiently dampening out.

A word length counter selects the serial parallel decoder to be described and, together with the CAMAC command decoder, causes the switching of the output multiplexer. Circuits blocks are still located on the interface card. With these blocks a preselection of the integration period of the sensor and a decrease of the image data read-out rate can take place.

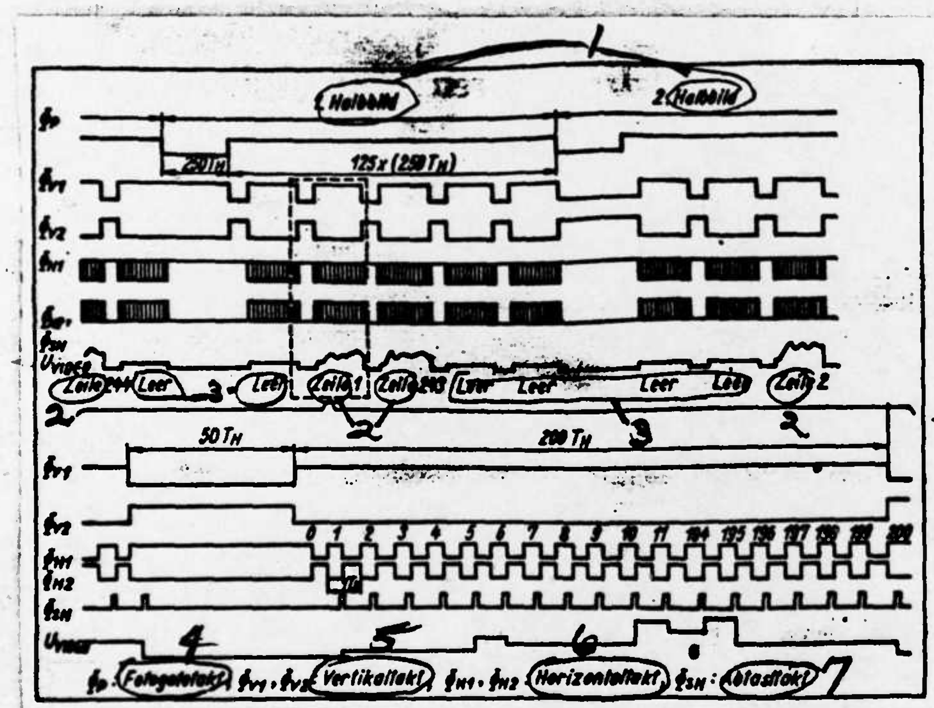

Figure 2. Timing Diagram

1. Half Image
2. Row
3. Empty
4. Photo Gate Timing
5. Vertical Timing
6. Horizontal Timing
7. Scanning Timing

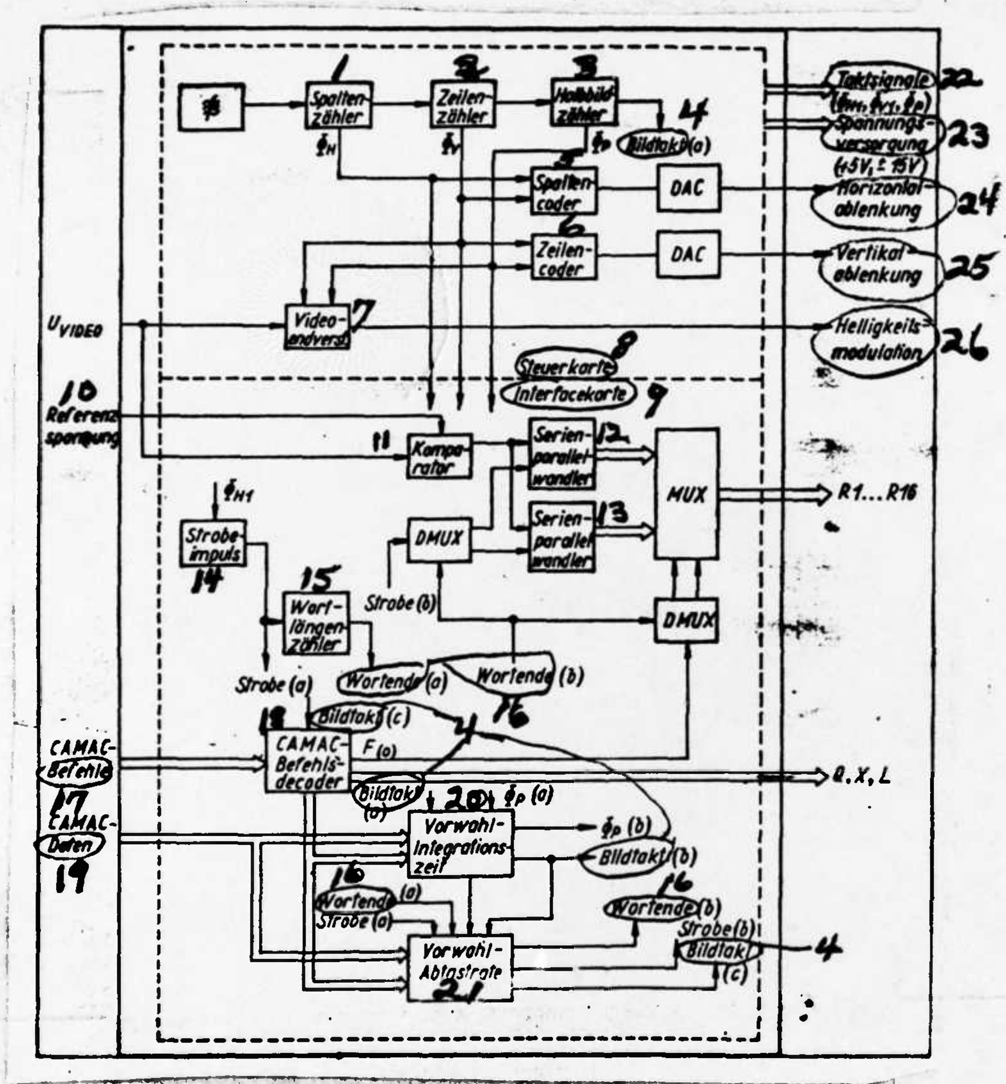

Figure 4. CAMAC Camera Module

1. Column Counter
2. Row Counter
3. Half Image Counter
4. Image Timing
5. Column Coder
6. Row Coder
7. Video Terminal Amplifier
8. Control Card
9. Interface Card
10. Reference Voltage
11. Comparator
12. Serial Parallel Converter
13. Serial Parallel Converter
14. Strobe Pulse
15. Word Length Counter
16. Word End
17. Command
18. CAMAC Command Decoder
19. Data
20. Preselection Integration Period
21. Preselection Scanning Rate
22. Timing Signals
23. Power Supply
24. Horizontal Sweep
25. Vertical Sweep
26. Intensity Modulation

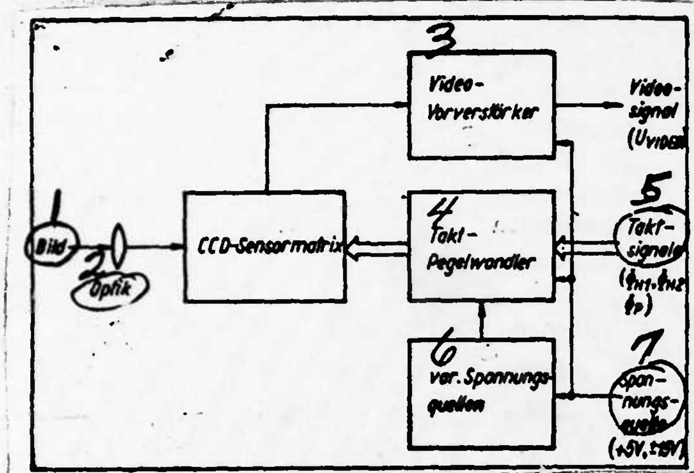

Figure 3. CCD Camera Block Schematic

1. Image
2. Optics
3. Video Amplifier
4. Timing Level Converter
5. Timing Signals
6. Variable Voltage Sources
7. Voltage Source

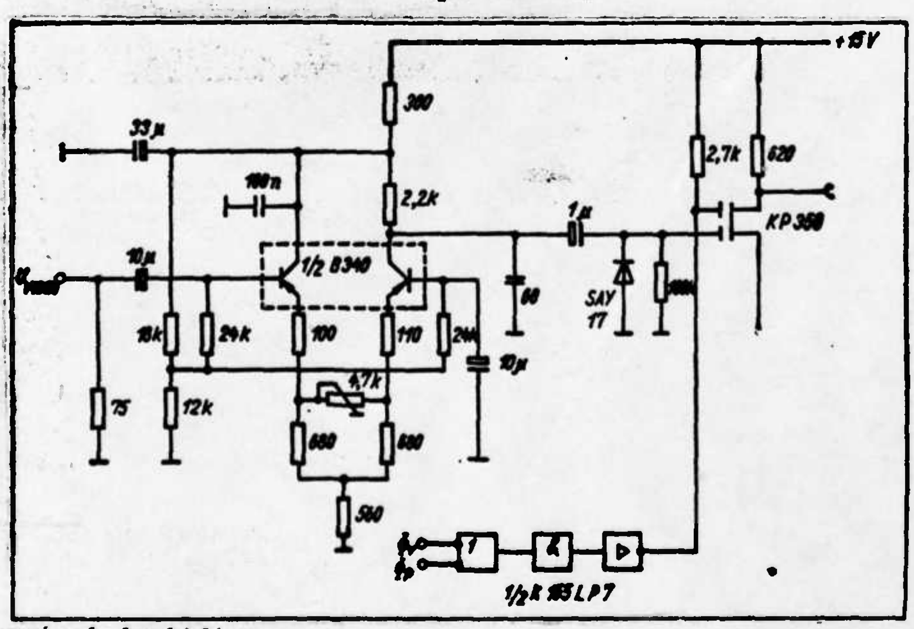

Figure 5. Video Terminal Amplifier

Figure 6. CCD Image of a Whirling Body with Radioscopy

3. Application Example

The usage of television in representing images on the secondary fluorescent screen of a X-ray amplifier (converter element) with radioscopy operations today belongs to standard technology. As a result, a continuous representation of the image of the X-rayed body is possible.
The application of X-ray television is more difficult when it concerns storing, processing and documenting the image. The production of a complete X-ray television image requires the summation of approximately 10 image scannings. The physical properties (noise, inertia) of the iconoscope (e.g., terminal icon) inhibit capturing a complete individual image in one scanning cycle. For this reason, initial investigations were performed on the X-ray amplifier with the described device design [13]. Thus, for example, the representation of a X-rayed whirling body shown in Figure 6 can be obtained. The poor image quality compared to television results, among other reasons, from the monitor representation on a intensity modulated oscillograph. The sensitivity better than 1.10^{-2} lx.s leads to improved time resolution of the quickly executing processes in the X-rayed body. Basically, the application of CCD camera designs is possible on the secondary fluorescent screen of an X-ray amplifier. Proceeding from the described sensor density and matrix size, a direct

practical conversion appears still premature.

4. Concluding Comment

The camera system described here is the initial step of a closed system with CCD sensors usable for multiple applications. Further development has to take place in the direction of higher amplitude resolution. In order then to still be able to operate the camera at optimal operating frequencies, a buffer memory is to that end required for the primary image data because no real time image processing can be performed with the described version. For such a case, compatibility of the camera system would then be conceivable, for example, to the image storage of the image processing system A 647x of the Public Owned Corporation Kombinat Robotron [14].

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12

Understanding Path-Time Characteristics with a Discretely Assembled Sensor Scanning Strip

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Understanding the dynamic behavior of precision mechanical components depends on how exactly and, primarily, on how quickly, for example, manipulative and positioning processes can execute. Evaluating the path-time behavior, for example, of a gear element (lever, rod, etc.) is indispensable for the application of the corresponding measuring technology. For this, multiple measuring methods are available with non-contact and reactionless measuring being of primary interest because no adulterations of the measuring values can occur, for example, through additional measurements required in other methods. Sensors originated with the development of optic-electronics. These sensors are well suited for a non-contact and reactionless measuring method. These are individual elements such as photo diodes and transistor; however, they are, for the most part, one dimensional (CCD row, MOS photo diode array) and two dimensional (CCD matrix) sensors [1] [2].
One and two dimensional sensors can also be assembled discretely. An example of this is presented in the following.

1. Measuring Possibilities with Linear Sensors

Linear sensors can principally be applied to the solution of the following problems:

- Recognition of the position and geometry of suitable objects
- Character recognition
- Non-contact measuring (scanning of light dark edges)

CCD rows are capable of storing analog values. For this reason, they can be applied not only to character recognition but also to image recognition. The recognition of two dimensional images of objects occurs through linear image scanning, assuming a relative movement between the image and sensor scanning strip. In order to avoid this relative movement, two dimensional sensors can be applied. Thus, [3] reports on the application of a single chip CCD sensor with 570 horizontal and 490 vertical elements for imaging in a reflex camera. Frontal projected light dark edges were used for plotting the s(t) curve of moving objects because the distortion interval is lengthened on the basis of these digital operations.

The position of the light dark edges moving during the process to be understood can be interrogated many times. In this manner, a execution diagram results which can also take into account multiple light dark edges. The number of read-out processes determines the time resolution of the movement process. Solid state image sensors have the advantage that multiple light sensitive elements are implemented in a small space. Resolution and accuracy are determined through the number of sensor elements and the size of the object field. Because in the majority of applications the object size requires an optical reduction, the image measuring scale must additionally still be taken into consideration. Errors in the lens and diffraction effects cause negative results. A correction possibility using a micro processor and an error matrix in memory is discussed in [4]. MOS diode arrays have the advantage compared to CCD rows that the timing preparation is simpler and an integration period is unnecessary. During this integration period, proportional charges are stored in the light sensitive elements of the CCD row of the illumination intensity.

The CCD scanning strip L 110 C manufactured by the Public Owned Corporation for Television Technology in the Public Owned Corporation Kombiant Micro Electronics contains 256 elements. For many applications, this image point-like resolution is completely sufficient. The time resolution achievable is approximately 30 micro seconds; that is, the stored information of the 256 elements can be interrogated once within this period. Nevertheless, the output voltage is still only 5 % of the saturation voltage when illuminating with standard light type A (300 micro W/cm^2) and an integration period of 100 micro seconds [5].

Five timing components are necessary to operate the L 110 C. On the basis of multiple application possibilities, this scanning strip is employed frequently, particularly in so-called CCD cameras. For many applications where this type of high image point-like resolution is unnecessary, the application of discretely assembled linear sensors presented in the following is, of course, also meaningful.

2. Experiences with a Discretely Assembled Sensor Scanning Strip

A special measuring problem defines the following requirements:
The movement process of interest can be understood on the basis of a light strip changing its width. On the total path length of 25 mm, it should be scanned 100 times. The width of the light strip is less than or equal to 5 mm. These types of measuring problems can also be solved with a moving recording camera [6]. This method naturally offers a higher resolution; it requires, however, a development of film material before the evaluation.

2.1 Assembly

The principle measuring assembly [6] is represented in Figure 1. In the place of the diaphragm, a sensor scanning strip can now be positioned. The continuous movement of film can be replaced by multiple read-out processes of the scanning strip during a movement process. Because the length of the sensor scanning strip corresponds to the total path length and the scanning plane was positioned directly behind the plane of motion of the elements adjacent to the light aperture, the lens is also no longer required.
On the basis of the resolution required, a minimum number of 100 scanning points was established. Because 100 discrete optic-electronic components, such as photo diodes or transistors, can not be placed in rows one behind the other on a 25mm length, it must be verified whether the defined arrangement of light conducting fibers can contribute to the solution of the problem. The available Plast light conducting fibers had a diameter of approximately 280 micro m. As a result, a single row arrangement in the 250 micro m raster can not be implemented. The fixed positioning of the fibers occurs, as shown in Figure 2, in one plane because it can be assumed that the light dark corners to be recorded are always perpendicular to the direction of motion. The positioning of the borings in a bedplate corresponding to Figure 2 can be achieved with a coordinated table drilling machine. Considerably smaller positioning deviations of 5 micro m can be achieved with a Nd^{3+} YAG laser. The smallest programmable

interval was 10 micro m.

A related structured Cu foil is shown in Figure 3. The quadratic aperture geometry (length of edge 300 micro m) was selected due to the simpler programming of the processing. A correspondingly thicker material can be processed with higher performance lasers. Thus, the guiding of the fibers is improved. The fibers must be as fixed as possible in such a manner that the sectional plane of the fiber ends is perpendicular to the fiber axis. If the light does not occur in the direction of the fiber axis, then the damping is greater on the basis of the higher number of reflections on the surface of the fiber cover. The coupling of the fibers to the corresponding sensors (in this case, photo transistors SP 201) is proven as non-problematic. More and more fibers are carried on a transistor. Instead of 100 transistors, it is sensible to apply fewer and to employ them multiple times.

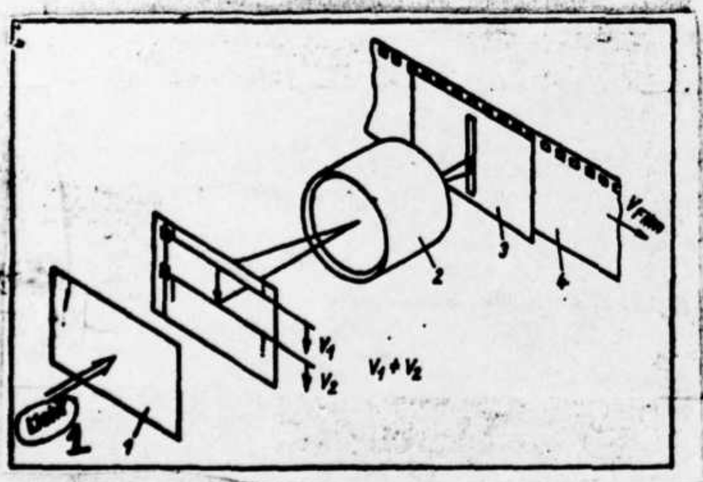

Figure 1. Measuring Arrangement with a Moving Recording Camera [6]
(1 Ground Glass Plate; 2 Lens; 3 Diaphragm; 4 16 mm film)

1. Light

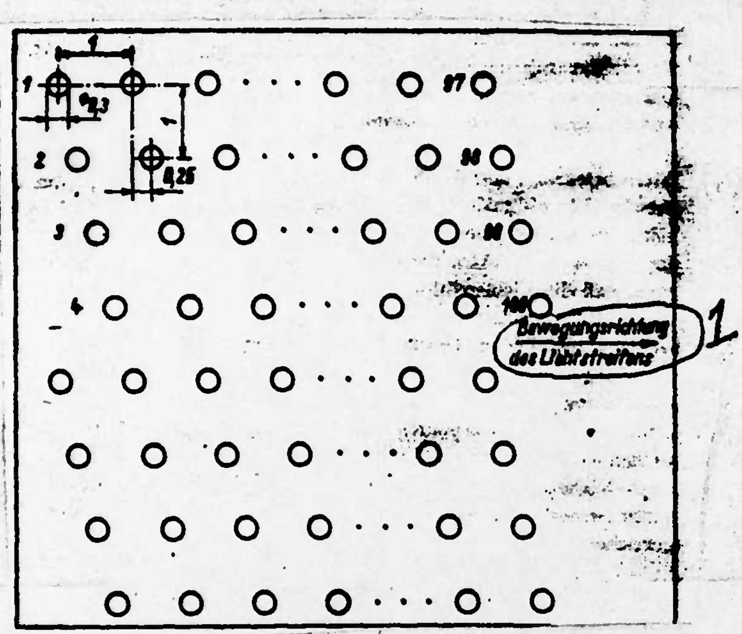

Figure 2. Arrangement of the Light Conducting Fibers
1. *Direction of Movement of the Light Strip*

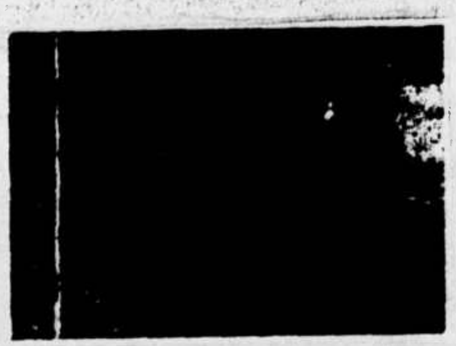

Figure 3. Cu Foil with Laser Structured

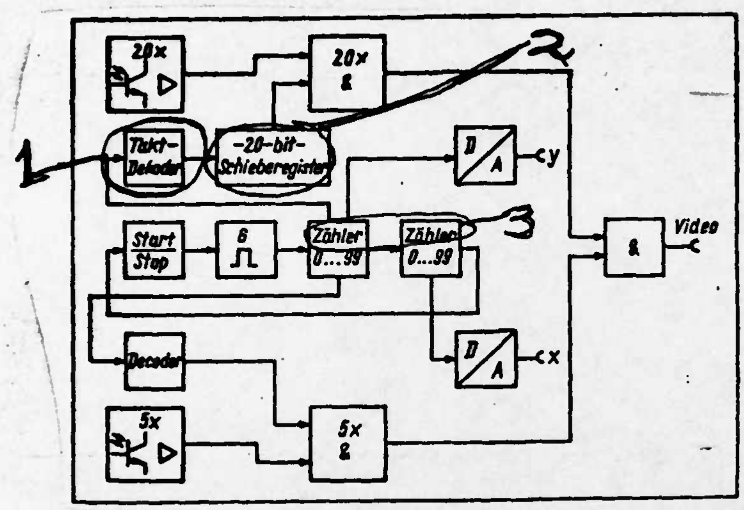

Figure 4. Principle Assembly of the Evaluation Electronics

1. Timing Decoder
2. 20 Bit Shift Register
3. Counter

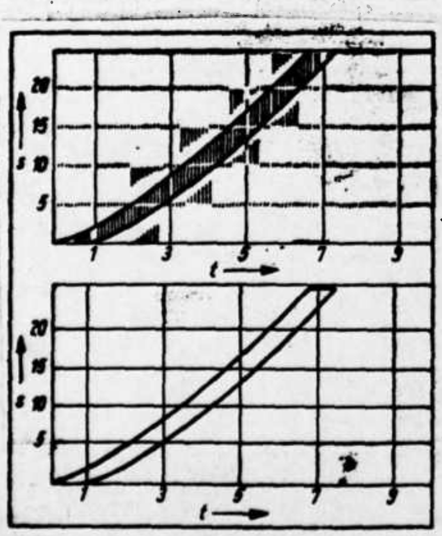

Figure 5. Recording Curves

a) corresponding to a recording with the described sensor scanning strip (the border of the curve is drawn in)
b) corresponding to a recording with a moving recording camera [6] (curve ≙ to the exposed portion of the film)

In this regard, we proceeded on the basis of the following considerations: The width of the travelling light aperture is never larger than 5 mm. Thus, the entire length of the scanning strip of 25 mm can be divided into five segments because less than 20 adjacent fibers are always illuminated.
It is, therefore, possible to suffice with 25 transistors because every first, second, ... twentieth fiber of the five segments is coupled to the first, second, ... twentieth photo transistor. Five transistors provide for the recognition of the segment currently illuminated. Here 20 fibers of one of the five segments are coupled to each transistor; i.e., that another 100 borings must be included parallel to the other ones in the bedplate due to the interval recognition (Figure 2).

2.2 Evaluation Electronics

The important component groups of the evaluation electronics are shown in Figure 4.
A timing generator of a frequency f = 1 MHz controls a counter consisting of four counting decades. With the counter, 9999 counts are realized. This frequency results according to equation (1) from the measuring time t_m = 10 ms, the image count Z_B = 100 and the number of the rows Z_z to be formed adjacent to one another, for example, on an oscilloscope screen. In this case, Z_z = 100:

$$f = \frac{Z_B\, Z_z}{t_M} . \qquad (1)$$

The control voltages for the X and Y diffraction of the oscilloscope acquire two digital analog converters from the BCD coded outputs of the counting decades mentioned previously. A suitable decoder makes possible, furthermore, the activation of one of the 20 gate circuits. As a result, the condition existing at the corresponding position of the five segments is interrogated. A 1 out of 5 decoding still takes place to ensure accurate positioning. The decoding implements the corresponding individual signal segment arrangement. The possibility of focusing a measuring raster is not presented. By attaching an external generator, the measuring time can be varied. The first illuminated fiber triggers the measuring process.

2.3 Measuring Example

With the acquired video signal, the beam dark controlling occurs when photographing with a memory oscilloscope or controlling lowering the pen occurs when outputting on the X-Y plotter. A 10 K-bit digital memory was assembled for intermediate storing of the video signal.
Figure 5 shows the comparison between a curve of motion to be produced in accordance with [6] and one produced in accordance with the described method. The first one assumes a film development and enlargement; the second one can be represented directly with an X-Y plotter. The corners seen in Figure 5a above and below the curve result from the simple assembly of the evaluation electronics and do not lessen the expressiveness of the curve. When transferring from one segment to the other, both segments recognition transistors were illuminated over a portion of the 20 light conduction fibers each and, as a result, the corresponding individual signals of both segments were also declared as valid. Addressing now the representation of the additional corners: they merge with the curve under the condition that the width of the light aperture corresponds at least to the segment width. This situation must be taken into consideration for the purpose of multiple usage of the photo transistors in meaningful regions when dividing or be eliminated through increased circuit technological efforts. The comparison of the two curves shows that the selected number of scanning positions characterizes the process both sufficiently and exactly.

3. Summary

For a series of applications such as path scanning over a longer length with a small required resolution, it is sensible to fall back upon a discretely assembled sensor cell instead of a CCD scanning strip. Principally, it is also possible, as a result, to assemble two dimensional sensors which, among other reasons, can be of interest for position recognition or geometry recognition of simple parts.
The digital operation makes possible a relatively simple evaluation using micro processors as the basis of fully automatic testing and adjusting processes. Furthermore, it is advantageous that discretely assembled sensors can

scan paths along arbitrarily curved lines. There are also solvalbe measuring problems, such as understanding the relative motion of two rotating disks to each other. Until that time when two dimensional sensors can also offer an economical alternative for applications with low required resolution, the method describe, when CCD scanning strips were not yet available, should be a suggestion.

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